§3. Development of *Ka*-band Ultrashort Pulsed Radar Reflectometer for Electron Density Profile Measurement

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Recently we have been developing a new type of reflectometer which is used an ultrashort sub cycle pulse. It is called as an ultrashort pulsed radar reflectometer. An ultrashort pulse has broad band frequency components in a Fourier space. It means one ultrashort pulse can take the place of a broad band microwave source.

The ultrashort pulsed radar reflectometer system was shown in the previous annual report. An impulse of -2.2 V, 23 ps full-width half-maximum is used as a source. To extract the desired probing range of the frequency, we utilize a *Ka*-band rectangular waveguide. When the impulse is launched into the waveguide, it is transformed to the chirped wave including broad frequency components. It is caused by the dispersion effect of the electromagnetic wave in the waveguide. The output chirped wave from the waveguide is amplified by a power amplifier and then is launched into the plasma. The incident wave reflects back from the cut-off layers corresponding to each frequency component. The reflected wave is mixed with 42 GHz continuous wave of the local oscillator. The output from the mixer is amplified by the intermediate frequency (IF) amplifier (2 – 18 GHz) and then divided to ten. Each IF signal is filtered by band pass filters which the centre frequencies are 3, 5, 6, 7, 9, 10, 11, 12, 13, 14 GHz and they correspond to 39, 37, 36, 35, 33, 32, 31, 30, 29, 28 GHz, respectively, in the incident frequency components. The ten signals are detected by the Schottky barrier diode detectors to obtain the reflected signal pulses. The reflected pulses are amplified by pulse amplifiers and leaded to constant fraction discriminators (CFD). A part of the incident wave is extracted with a directional coupler and is detected to obtain the reference pulse. Both the reference pulse as the start signal and the reflected pulse as the stop signal are leaded to the time-to-amplitude converter (TAC). The output voltage of TAC is proportional to the time difference between the start and the stop signal. The spatial ambiguity estimated from the TAC output has been tested and defined lower than 6 mm.

By using the ordinary wave the measured flight time of each frequency pulse reflected from the plasma has been described by

$$\tau_p(\omega_0) = \left(\frac{\delta\phi(\omega)}{\delta\omega}\right)_{\omega=\omega_0} = \frac{2}{c}\int_{r_a}^{r_c(\omega_0)}\left(1-\frac{\omega_{pe}^2(x)}{\omega_0^2}\right)^{-1/2} dx\,, \qquad (1)$$

with r_a the edge of the plasma, c the velocity of the light, ω_o the probing frequency, ω_{pe} the plasma frequency, and $r_c(\omega_o)$ the position where the plasma frequency equals the probing frequency, respectively. The result of the time evolution of TOF measurement is shown in Fig. 2. The delay time is defined by the travelling time from the assumed plasma edge to each cut off layer. When the corresponding cut-off layer is generated in the plasma, each reflected wave is observed in order. By using Abel inversion the position of the reflecting layer is given by

$$r_c(\omega_0) = \frac{c}{\pi}\int_0^{\omega_0}\tau(\omega)\Big/\sqrt{\omega_0^2-\omega^2}\; d\omega \quad . \qquad (2)$$

Figure 3 shows the time evolution of the reconstructed density profile. In this inversion the cubic spline interpolation is used for connecting the data points between the lowest frequency cut-off layer and the assumed plasma edge.

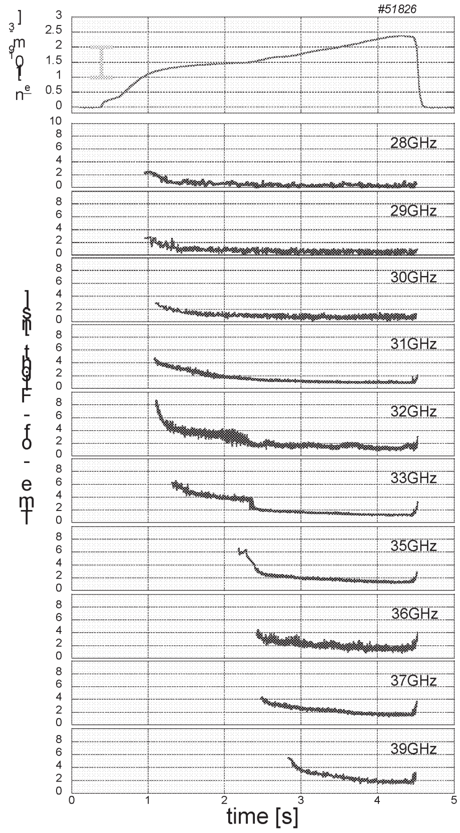

Fig. 1. Time evolution of the averaged density (top) and the delay time of the reflectometer each channel.

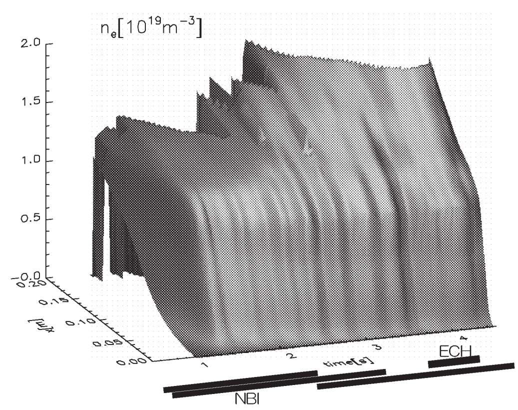

Fig. 2. Time evolution of the reconstructed density profile